

2 The Design Process

Introduction

There are strategic stages in the design process used by all experienced designers, but not always consciously articulated, which if well understood, certainly express the challenge and delight in engineering. Given a statement of such principles and examples of their use, it is of value to show how to design projects in a systematic manner, integrating detailed technical competencies as particular disciplinary postulates, as distinct from fundamental axioms or principles. In this chapter this systemic process is set out and illustrated.

There can be said to be a hierarchy of principles: from the general to the particular. In this book we are setting out the general strategic principles concerned with the process of design. There is a need for collaborative team work, with “brain-storming” interdisciplinary design sessions. The managerial skills and resources to assemble and control large numbers of people over periods of time are essential components of effective design practice.

Senior engineers are actively engaged in primary decision-making activities. They encourage freedom of thought in the context of structured programmes. They understand the nature of this stage in the meeting of human needs, and have developed the ability to envision solutions to defined needs, and then to ensure the delivery of these solutions.

The abilities of the engineer can make a valuable contribution to primary decision-making. Primary decision-making is the first step in design. It begins with the fundamental decisions as to the need to be met. As engineers it is important that we recognise that this stage benefits from, and indeed requires, a professional engineering contribution. Paradoxically, because of our great success in the delivery process, we have reduced our contribution to primary decision-making by associating the

design activity with the development of decisions made by others. This book attempts to increase the awareness of the engineer as to the primary stages of design in meeting society's needs.

During my early years as an engineer, a small group of my contemporaries met regularly each week at lunchtime to present our work for the benefit of each other. This professional enthusiasm continued, and the members of the group remained in touch with one another for over 50 years. This interest in our work is not untypical of young professionals and contributes to the transfer and development of skills and experience.

Design is the essential creative process of engineering, which distinguishes it from science, and which calls for imagination and creativity, as well as the knowledge and application of technical and scientific skills and the skilful use of materials. It is particularly important that the general and interdisciplinary aspects of design be demonstrated and recorded at every stage in the design process. The teaching of design has an integral place in the formation of all engineers, particularly with the increased understanding of the importance of considering sustainability and environmental and social impact.



The Nature of Design Principles

Engineering design can be considered as encompassing three stages. The definition of the need to be met, the conception of a response to that need, and the organisation and management of the delivery of that response. These three areas of activity can be summarised as:

1. The definition of need, requiring the recognition and understanding of the nature of society, of economics, of humanity's needs. The human qualities of reason, compassion, service and curiosity all contribute to the definition of need. **All design begins with a clearly defined need.**
2. The use of creative vision, requiring the ability to think laterally, to anticipate the unexpected, to delight in problem-solving, to enjoy the beauties of mind as well as of the physical world. The ethos within which the problem is being addressed must be understood. **All designs arise from a creative response to a clearly defined need.**

3. The delivery of a solution to the recognised need, requiring the assembly and management of resources and of team members with the necessary skills and knowledge of natural laws, and of the materials and energies needed to effect an efficient and appropriate creative design. **All designs result in a system, product or project which meets the need.**

Design is recognised as an iterative creative process bringing about the development – physical and cultural – of ways of meeting identified needs. The formulation of clear definitions of perceived needs and processes is emphasised and illustrated in the twelve case studies in Chapter 4.

The principles of need, vision and delivery describe fully the role of the designer in all disciplines, not only in the application of the understanding of natural laws and of the analytical processes, but also in the expressed understanding of the societal context. Design is an iterative but controlled process – effective creativity. The need for clarity of definition and control of aims is clearly demonstrated in the examples analysed.

An understanding and knowledge of principle are essential if design decisions are to produce desirable results. In engineering terms a desirable result is likely to be a useful physical entity or system, valuable in meeting some need and improving the quality of life of individuals or of communities.

The Oxford English Dictionary defines a principle as:

- Origin, source; source of action
- That from which something takes its rise, originates, or is derived
- A fundamental truth or proposition, on which many others depend; a fundamental assumption forming a basis of a chain of reasoning.

In engineering it is possible to identify basic principles which can be referred to by all designers of any discipline when initiating their work, or testing the quality of design decisions, whether their own or another's. Such fundamental principles are not to be confused with the postulates, definitions, hypotheses, standards or rules included as part of the technical training and ability of the professional engineer. Such technical formulations are of value in particular instances, and are well known and formulated in engineering practice.

The “principles” presented are not the purely scientific hypothetical principles, such as the laws of statics, dynamics, thermodynamics or electro-magnetism, which are already an essential part of the engineering curriculum. These fundamental principles are intended to provide

the total context for good design. They are not necessarily rooted in physics or mathematics, and derive more from experience and practice than from formal theory. They are the substance of professional engineering judgement. An understanding of these basic principles enables an engineer to engage in the highest level of decision-making, to which he can then bring his professional skill and training.

Engineering design involves many parameters upon which the success of the project depends, and each of these specific areas of concern has its own sub-set of laws, standards, practices, codes and regulations. The volume and detail of these particular constraints and directions can make it difficult to appreciate the fundamental principles, which may be well known to experienced designers, but may not have been clearly formulated. The case studies show the relationships and differences between the specific and the general principles by demonstrating these at each step in the design development.



Practice of Design

In practising design the process develops from stage to stage. The factors to be considered at each stage – need, vision and delivery – have been formulated as checklists for use in the early stages of design as follows:

Formulation of Need

- The cultural societal and physical ethos in which the project is to be carried out
- The history of the project, how did the perception of need arise?
- The decision-making structure – social, client, design management
- The human resources available – professional skills, research, available craft skills
- The physical, technical and economic resources available
- Sustainability requirements, energy sources, environmental impact
- Relevant research and development
- **The clear formulation of the need**

Human needs can arise from many sources. They can be recognised politically, economically or socially. The first thoughts may reflect an

individual awareness of need, or a professional awareness, linked with a justifiable wish for a fee or contract.

It is of value to consider the several points listed above, and to set these down as they relate to a particular awareness of need. Collectively, they will provide the basis of a “brief” for the project or system, and a review of the context. This will involve an exchange of views with others, but at this stage only a limited number of interested parties will be concerned. The final definition of need will be best expressed in a single, clear sentence.

The designer’s skills must be related to social and contextual factors to be effective. He or she is not engaged in abstract research or exploration, but in directly improving the quality of life in society. The care and well-being of the community are of paramount importance, requiring a sympathy and comradeship with others. A sense of humour and the enjoyment of the company of others are of great importance. The needs to be met are human needs.

The brief schedule of factors to be considered during this stage of design reflect these human interests and require an understanding of the interaction between others. Our technological skills enable us to serve these interests.

An example of this social dimension was evident in the siting of the University of Surrey in Guildford. The first Vice-Chancellor of the University – Dr. Peter Leggett – was concerned that the university should become part of the fabric of the community, not an isolated institution. We identified alternative sites for the university, one on the slopes to the north of the Cathedral on Stag Hill, and the other on the fields to the west, beyond the motorway. The latter was technically a much better building site, but the former was within a short walk of the city centre. This site was chosen and the technical skills used effectively to stabilise the slope and overcome the building problems.

I recall meeting with Dr. Leggett and discussing the purpose and aims of the university, which we formulated as: “to enable the individual development of the students and equip them to serve the community”. The proximity of the city was an important part of meeting this need. The meeting had emotional, caring aspects as well as the formulation of the professional brief. It provided the quality of energy and commitment needed to support the project during the 4-year design and construction programme. Dr. Leggett and I pinned this aim to our study walls for the period of the project development!

Creative Response – the Vision

This stage can be considered as in two parts: the definition and understanding of the social and physical context within which the need must be met, and the development of creative vision of how the need might be met within that context. The key factors of these two sub-divisions of the visionary process are set out below.

Contextual Constraints

- Establish relationships with client team and socially affected groups
- Selection of team with necessary professional competence, knowledge of natural laws
- Surveys of context – physical, climatic, topographical, materials, energy
- Legal requirements – planning permissions, legislation.
- Funding and value for investment, competition
- Programme requirements
- Health and safety issues
- **Summary of contextual items**

The context within which the need is to be met must be appraised. A thorough review of all the factors listed above is essential. This will include physical and social parameters: topographical, economic, climatological, social, historical, *etc.* These should be set down in a contextual report, and referred to during the creative design stage. They may involve the services of specialists (surveyors, geologists, economists, lawyers, planners) working as part of the overall design team.

Care should be taken *not* to attempt to formulate a design before the constraints have been considered. Premature conceptions are frequently abortive!

Effective Creativity

- Interdisciplinary discussions
- “Brain storming” sessions
- Preparation of alternative imaginative schemes
- Programme for delivery
- **Selection of a preferred solution and its clear definition**

This stage of “visionary” design can be the most significant and important of the whole process. The placing of the formulation of the need within the context is the first step. The selection of a suitably experienced, talented and well-trained group of designers, capable of effective interdisciplinary discussions and of working together, is essential. It may be valuable to call on particularly experienced and talented designers who are not part of the main project team, but who can make particularly relevant contributions to the creative design process. The team leader must be a good listener, and sufficiently respected by the group for them to accept his directions.

In 1992 an invitation was received from the Soviet Academy of Science for two senior engineers from the UK Royal Academy of Engineering to visit Russia and advise young Russian engineers on how to work with a market economy. This proved very interesting in increasing our awareness of the contrasts between the centralised communist government and the free market economy. An illustration of this came in a major meeting in St. Petersburg with the senior management of a very large and well-equipped naval research institute, employing about 3000 highly qualified staff. When we suggested that the organisation might be subdivided and liaise more closely with European institutions, the chief executive was very concerned – he asked, “How will I remain in control?! ” The delegation of responsibility was not part of their established culture.

It is sometimes helpful to have group “brain-storming” sessions away from the usual office demands. Given good support (flip charts, computers, admin and other support staff) the freedom to work together can be very creative. A number of conceptual designs may be developed and compared. The inspired designer should enjoy the whole process. As an example of the importance and value of being aware of the situations in which we find ourselves, the following note on one of the “inspirations” arising from observation may be of interest.

In designing the terminal works for the Channel Tunnel it was necessary to consider the random movement of high traffic flows with a variety of apparently independent drivers. Observing one day from a high level footbridge at Cannon Street Station the movement of pedestrians leaving a train and descending to an underground pedestrian tunnel, it was clear that whilst they all felt that they were making decisions, they were actually following a turbulent flow pattern from their trains to the tunnel. We therefore adopted a turbulent flow

analysis for the traffic arriving at the tunnel terminal and found that it enabled us to develop a traffic management system which works well.

The selection of a preferred solution from the several that may be proposed is very important, and, as was the case with the formulation of the need, it should be clearly defined and well illustrated with good conceptual drawings and diagrams. This vision will form the starting point for the delivery process. It should include a viable budget and programme. It must be acceptable to all the relevant authorities and fully understood by the client body.

The accepted vision can be displayed on the office walls of all those involved in the production and delivery process.

Delivery

- Agreement and documentation of preferred solution – continuous reviews of delivery against aims – the design audit
- Definition of management team and process of delivery
- Selection of key designers, of contractors, sub-contractors, and specialists
- Definition of their roles
- Reference to interested third parties
- Agreement on financing – budget, cash flow, cost control procedures
- Agreement on delivery programme
- Agree contract procedures
- Assembly of project/product resources – skilled crafts, materials, equipment
- Agree quality management procedures – design, manufacture, construct
- Health and safety considerations
- Legal requirements and programme
- **Hand over to clients**

This stage in the realisation of the solution to the need usually takes up the major part of the whole project programme. The delivery process will also be the period of greatest expenditure.

The selection of an experienced and strong project team is essential, capable of bringing together the many specialists involved in the process and of ensuring that the accepted design is not allowed to be changed for short-term expedencies.

Collaborative work is essential in an emergency. During the construction of the oil refinery at Grangemouth in Scotland there was a major incident one weekend when there were no workmen on site. The chief contractors engineer and the young supervising engineer spent several hours excavating in some foundations threatened by settlement. The safety of the work was more important than their respective professional roles.

It is important to set out clearly the project structure and the relationships between the various team members, particularly those between the different disciplines (client, user, lawyer, politician, planner, economist, architect, engineer, *etc.*) and to emphasise the formulated need being considered and the resources necessary and available to meet this need.

Early site experience included night shift working on a major harbour project. The team worked together very closely on the driving of very large piles. When the piling rig broke down in the early hours of the morning the whole team went to their favourite pub and persuaded the publican to open at 2.30 am. As a very young supervising engineer I was included in this invitation, and was impressed by their collaborative concern for each other's safety, and for the quality of the work they did.

In developing a design it is essential to keep in mind these aspects of the process and to work in a systematic manner, with regular reviews of each stage to ensure that all aspects are considered. Under the pressure of programme and cost control, we may occasionally move forward and not cover all these points, leaving us with a less satisfactory conclusion.

It is usually advantageous to begin the delivery with presentations to all involved – the contractor's work force as well as senior management. It is encouraging to experience how interested all participants are in learning the history and creative processes that have produced the project. In some projects it can also be very helpful to inform interested third parties of the proposals: neighbours, local services, *etc.* This is indicated in the case studies in Chapter 4 of this book.

When beginning the construction of the University of Surrey in Guildford the contractors and the consultants gathered together the total work force, and we explained to them the basis of the design, and what we hoped to achieve. We then found that we were spoken

to frequently during our visits to the site by various workmen, with suggestions as to how the design might be improved in detail. This was very encouraging and gave us the feeling of operating as a complete team in the construction.

The ethical aspects of design: are of great importance. The changes to all those affected by the work and by the environmental impact need to be carefully considered and noted in the documentation of the developing designs.

Satisfaction of a difficult job well done. The construction of the major airfield in the Falkland Islands was a very demanding project. On the completion of the main runway on time the whole construction team lined the airstrip to greet the first flight in. The young site engineer was very moved to see these very tough workers celebrating this major achievement in tears.

Performance in Practice

With significant projects it is valuable to review their performance in practice.

This can suggest possible post-contractual improvements, and serve to make the users of the project aware of the considerations that led to its completion in a particular form. Such reviews can also be of value in other projects and add to the database of experience available to designers. The factors to be considered during a performance review are:

- Reassessment of design brief
- Possible design development
- Social impact assessment
- Client/user satisfaction
- Economic performance
- Maintenance/operational factors
- **Experience to incorporate in future projects**

The case studies given in Chapter 4 are set out against these principles and show how they apply both to very large and technically complex projects and to the simplest of projects, from the Channel Tunnel to individual but effective projects such as artificial limbs. The criteria are included in an appendix for use in practice.



Example of Case Study

A study of an apparently very simple example of decision-making is given below to illustrate the design process. Using the criteria for each stage as developed above, the process is shown for the selection of new chairs for a college in London.

Formulation of Need

- The cultural societal and physical ethos in which the project is to be carried out
- The history of the project, how did the perception of need arise?
- The decision-making structure – social, client, design management
- The human resources available – professional skills, research, available craft skills
- The physical, technical and economic resources available
- Sustainability requirements, energy sources, environmental impact
- Relevant research and development
- **The clear formulation of the need**

A private college in London is considering the acquisition of new chairs. It is important that the need is clearly understood before committing to the purchase of the many chairs needed. The college has some distinctly differing needs:

- There are about 250 students attending the school every evening and at weekends.
- There is a refectory which may be dealing with some 150 students at a time, but the use of chairs here is for short periods only.
- There is an attractive entrance hall with an adjacent library, and about 20 chairs are needed for these public areas.
- There is a large meeting hall which seats about 100 people, used occasionally.
- There are 20 classrooms seating about 20–25 students each.

Considerable mobility of chairs is required to suit the variable student needs.

It must be possible to stack chairs efficiently when not in use. Some variations in height may be desirable. All maintenance is by voluntary

workers, and must be simple and time efficient. Consideration must be given as to whether some chairs with arms are needed. Since students use these chairs for about two hours every evening, they must be comfortable. The students' ages vary from teenagers to octogenarians. About 300 chairs may be needed. Economy is of great importance.

Formulation of need: 300 chairs are required, easy to move, comfortable, attractive and flexible in their usage. They must be easy to maintain and durable.

Creative Response – the Vision

Contextual Constraints

- Establish relationships with client team and socially affected groups
- Selection of team with necessary professional competence, knowledge of natural laws
- Surveys of context – physical, climatic, topographical, materials, energy
- Legal requirements – planning permissions, legislation.
- Funding and value for investment, competition
- Programme requirements
- Health and safety issues
- **Summary of contextual items**

The specification must be agreed with the college organisers and user representatives. The number of chairs and their distribution must be agreed, and possible variations in type to suit the differing needs. Enquiries will be made to obtain information on the range of chairs available on the market. It may be helpful to consult experienced interior designers, and possibly to seek the experience of other similar colleges. Chairs available will be considered relative to the design and decoration of the various rooms: refectory, hall, large meeting room, and study rooms. Suppliers will be invited to tender, and to quote delivery programmes.

Effective Creativity

- Interdisciplinary discussions
- “Brain storming” sessions

- Preparation of alternative imaginative schemes
- Programme for delivery
- **Selection of a preferred solution and its clear definition**

The collected information and specifications will be gathered together and presented to a selection group of experienced tutors and administrators. Based on this discussion a decision will be made as to the chairs to be purchased. This will include cash flow and delivery programmes agreed with the College Treasurer. This will form the instructions for the delivery team, to be confirmed as acceptable by the suppliers.

Delivery

- Agreement and documentation of preferred solution – continuous reviews of delivery against aims – the design audit
- Definition of management team and process of delivery
- Selection of key designers, of contractors, sub-contractors, and specialists
- Definition of their roles
- Reference to interested third parties
- Agreement on financing – budget, cash flow, cost control procedures
- Agreement on delivery programme
- Agree contract procedures
- Assembly of project/product resources – skilled crafts, materials, equipment
- Agree quality management procedures – design, manufacture, construct
- Health and safety considerations
- Legal requirements and programme
- **Hand over to clients**

Several of the items in the checklist above will have been considered in the design phase, but will need confirmation by the suppliers. The detailed programme for delivery will be agreed to ensure minimal interference with the working programme of the college. This may be best done during the vacation period, and may include the disposal of the existing old chairs. A careful check will be kept on the quality of the chairs delivered.

The cash flow programme will have been agreed with the chosen suppliers and the College Treasurer.

Performance in Practice

- Reassessment of design brief
- Possible design development
- Social impact assessment
- Client/user satisfaction
- Economic performance
- Maintenance/operational factors
- **Experience to incorporate in future projects**

The need to consider the selection of new chairs has arisen out of a review of the existing stock. After completing the purchase of new chairs it is necessary to review the brief, and assess the specification for possible future chair replacement. The use of the chairs will be noted, and the opinions of the users obtained.

Summary of Design Procedure

- Agree programme with client, and the scope of work of the designer
- Assess and define need, checking against the basic criteria
- Review and define the context, arrange any necessary surveys, *etc.*
- Carry out as a team the creative design process
- Agree and define accepted design solution
- Clearly define delivery team and programme, including contractors/suppliers
- Monitor progress on a regular basis, with formal review meetings

Design Matters

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